TOWARD A DESCRIPTION OF ^{13}Be AND ^{14}Be

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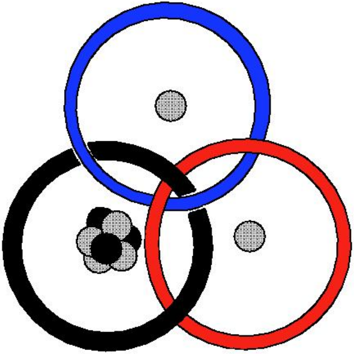
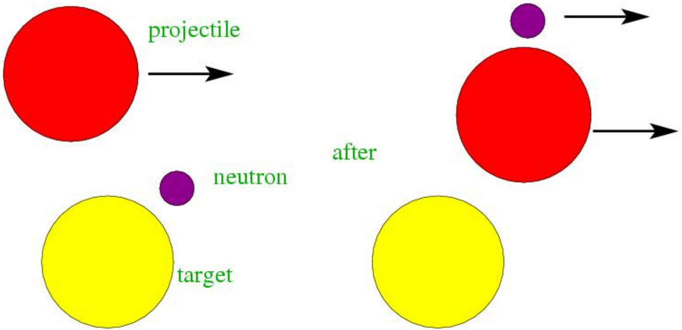
Plan of the Presentation

Halo nuclei

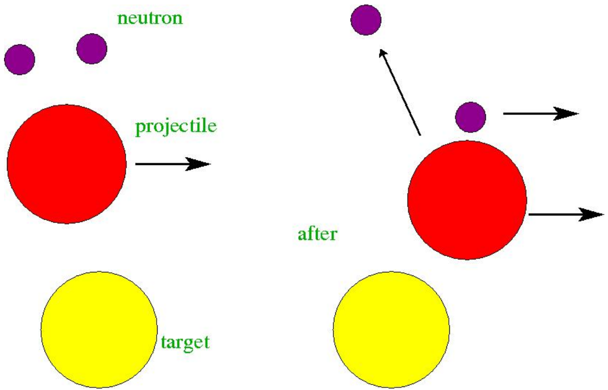


- One- or two- neutron halo nuclei
- Large spatial extention
- Two neutron halo: Borromean Systems
- three-body model
- importance of the n-core interaction

Transfer to the continuum reaction



Fragmentation reaction



The core-target movement is treated in a semiclassic way, but neutron-target in a full QM treatment.
AB and DM Brink, PRC38, 1776 (1988), PRC43, 299 (1991), PRC44, 1559 (1991).

$$\frac{d\sigma}{d\varepsilon_f} = C^2 S \int_0^\infty d\mathbf{b_c} \frac{dP_t(b_c)}{d\varepsilon_f} P_{ct}(b_c),$$

Use of the simple parametrization $P_{ct}(b_c) = e^{(-\ln 2 exp[(R_s - b_c)/a])}$, 'strong absorption radius' $R_s \approx 1.4(A_p^{1/3} + A_t^{1/3}) fm$.

Fragmentation

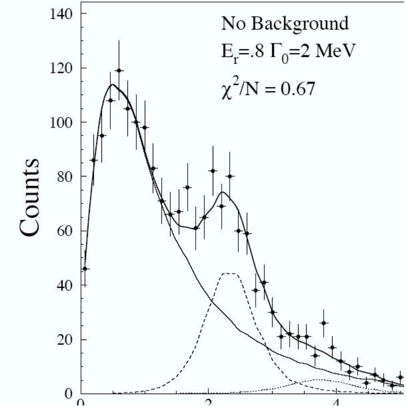


Figure: (a) LPC GANIL (Lecouey, Orr) (2002).

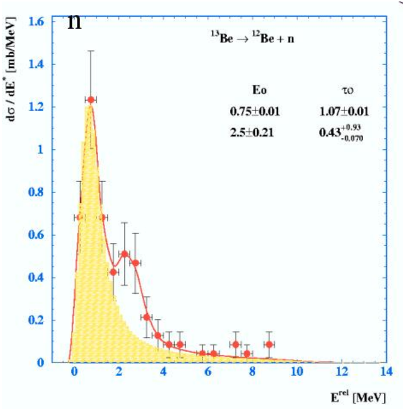
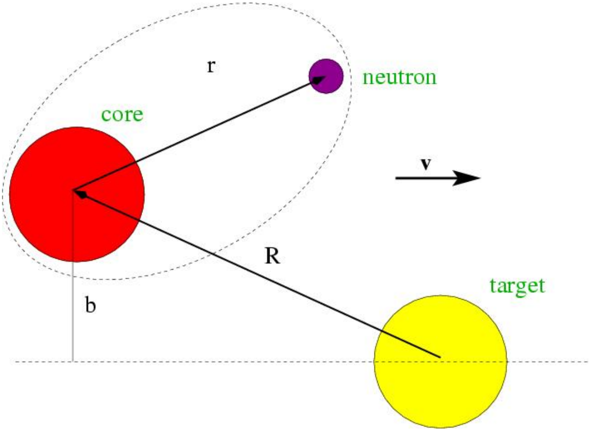


Figure: (b) GSI (U Datta Pramanik) (Surrey conference Jan.2005).

Inelastic excitation



Inelastic-like excitations can be described by the first order time dependent perturbation theory amplitude:

$$A_{fi} = \frac{1}{i\hbar} \int_{-\infty}^{\infty} dt \langle \psi_f(t) | V_2(\mathbf{r} - R(t)) | \psi_i(t) \rangle$$

In order to obtain a simple analytical formula we consider the special case $V_2(r) = v_2 \delta(x)\delta(y)\delta(z)$.

$$A_{fi} = \frac{v_2}{i\hbar v} \int_{-\infty}^{\infty} dz \; \psi_f^*(b_c, 0, z)\psi_i(b_c, 0, z)e^{iqz}$$

Asymptotic wave function

Initial state:

$$\psi_i(b_c, 0, z) = -C_i i^l \gamma h_{l_i}^{(1)}(i\gamma r) P_{l_i}(z/r).$$

Final continuum state:

$$\psi_f(b_c, 0, z) = C_f k \frac{i}{2}(h_{l_f}^{(+)}(kr) - S_{l_f} h_{l_f}^{(-)}(kr)) P_{l_f}(z/r).$$

Simple time dependent model

$$A_{fi} = \frac{v_2}{i\hbar v} \int_{-\infty}^{\infty} dz \; \psi_f^*(b_c, 0, z)\psi_i(b_c, 0, z)e^{iqz}$$

$$I(k, q) = I_R + iI_I = |I|e^{i\alpha}$$

$$\bar{S} = Se^{2i\alpha} = e^{2i(\delta+\alpha)}$$

$$|A_{fi}|^2 = C^2|I|^2|1 - \bar{S}|^2.$$

Comparison to the transfer to the continuum

Fragmentation:

$$\frac{dP_{in}}{d\varepsilon_f} = \frac{2}{\pi}\frac{v_2^2}{\hbar^2 v^2} C_i^2 \frac{m}{\hbar^2 k} \Sigma_{l_f} (2l_f + 1)|1 - \bar{S}_{l_f}|^2 |I_{l_f}|^2.$$

Transfer:

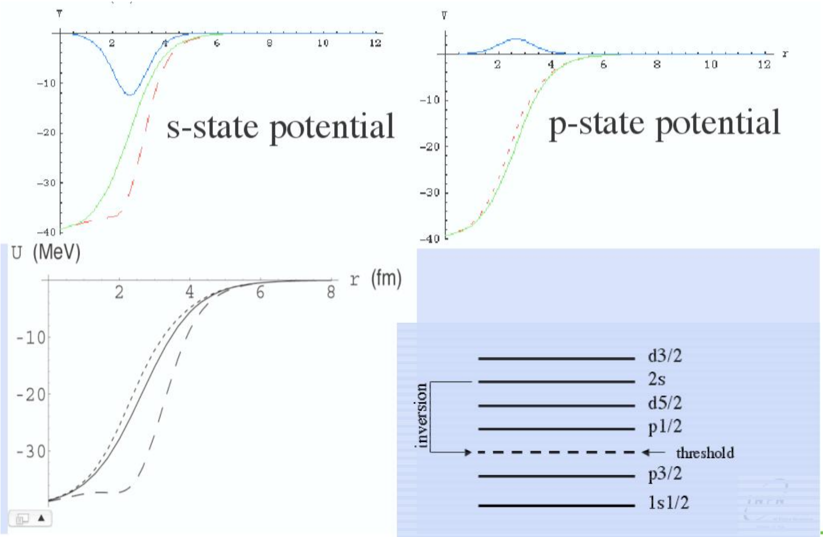
$$\frac{dP_t(b_c)}{d\varepsilon_f} \approx \frac{4\pi}{k^2} \Sigma_{l_f} (2l_f + 1)|1 - S_{l_f}|^2 B_{l_f,l_i}$$

Determination of the S-matrix.

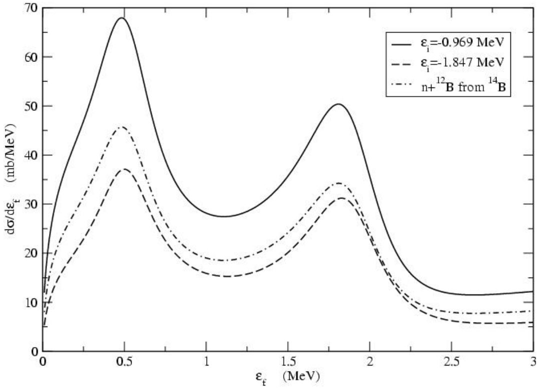
$$
\begin{aligned}
h &= t + U. \\
U(r) &= V_{WS} + \delta V. \\
\delta V(r) &= 16\alpha e^{2(r-R)/a}/(1 + e^{(r-R)/a})^4.
\end{aligned}
$$

V_{WS} = Potential Woods-Saxon + Spin orbit
δV = particle vibration-coupling
(N. Vinh Mau and J. C. Pacheco, Nucl. Phys. A607 (1996) 163.)

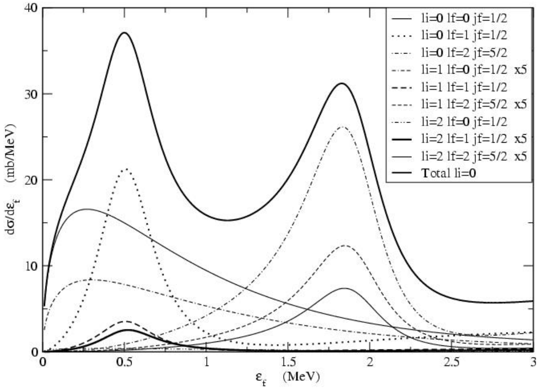
Potential correction.



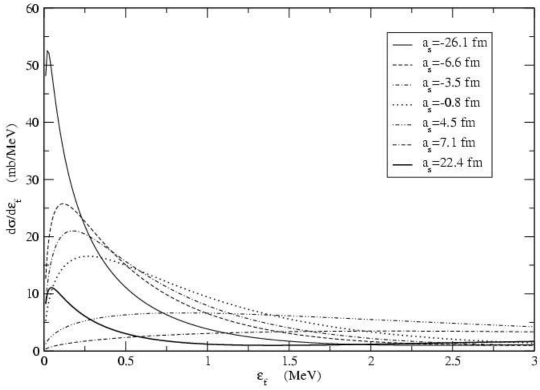
Dependence on the binding energy of the initial state



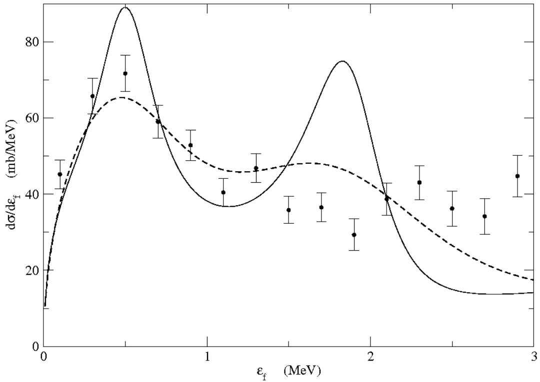
Strength of every transition



Dependence on the scattering length of the final s-state



Results vs. Experiment



Convolution of our results with experimental resolution made by Prof. Chulkov from GSI.

Conclusion

- ^{13}Be is a signature of the halo state of the neutron
- We need a low-lying p resonance in order to reproduce the experimental spectrum
- We do not take explicitly into account both neutrons
- The initial state can be improved
- Two steps: Second order calculation.

Particle-particle RPA

- Ingredients
  - neutron-core interaction
  - neutron-neutron interaction
  - core specificities
- Information obtained with the RPA
  - Two-body amplitudes between the core and the core $\pm$ 2 neutrons
  - S_{2n}(A) et S_{2n}(A+2)

RPA equations

For a given spin and parity the RPA amplitudes X and Y satisfy the system of equations:

$$(E-\epsilon_a)x_a - \sum_b \langle a|V_{nn}|b\rangle x_b - \sum_\beta \langle a|V_{nn}|\beta\rangle x_\beta = 0,$$

$$(E-\epsilon_\alpha)x_\alpha - \sum_b \langle \alpha|V_{nn}|b\rangle x_b - \sum_\beta \langle \alpha|V_{nn}|\beta\rangle x_\beta = 0,$$

with $a=(a_1,a_2)$ as a two-neutron configuration with the neutrons in states a_1, a_2... unoccupied in the Hartree-Fock core ground state, and α,β... as two-neutron configurations with the neutrons in occupied states.
(J. C. Pacheco and N. Vinh Mau, Phys. Rev. C65 044004 (2002).)

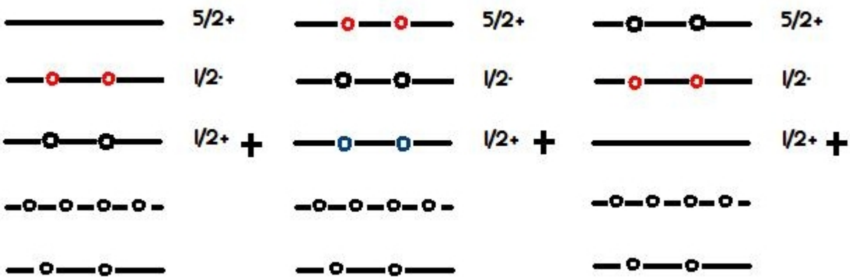
RPA amplitudes

$$
\begin{aligned}
X_{ab}^{(N)} &= \langle A+2, N | B_{ab}^{\dagger} | \tilde{0} \rangle \\
X_{\alpha\beta}^{(N)} &= \langle A+2, N | B_{\alpha\beta} | \tilde{0} \rangle \\
Y_{\alpha\beta}^{(M)} &= \langle A-2, M | B_{\alpha\beta}^{\dagger} | \tilde{0} \rangle \\
Y_{ab}^{(M)} &= \langle A-2, M | B_{ab} | \tilde{0} \rangle
\end{aligned}
$$

With the following orthonormalization

$$
\begin{aligned}
\sum_a X_a^{(n)} X_a^{(n')} - \sum_\alpha X_\alpha^{(n)} X_\alpha^{(n')} &= \delta_{nn'} \\
\sum_a Y_a^{(m)} Y_a^{(m')} - \sum_\alpha Y_\alpha^{(m)} Y_\alpha^{(m')} &= -\delta_{mm'}
\end{aligned}
$$

Illustration



- Advantages
  - The particle-particle RPA takes into account the two-body correlations in the core beyond HF.
  - It gives amplitudes , we need tools to determine: rms, transition probabilities, deformations.
- Goal
  - We look also at ^{12}Be as ^{11}Be structure is known, it is a good test for the model.
  - We calculate the caracteristics of ^{14}Be to constraint the ^{13}Be structure which is not well known.

Mean value of one- or two-body operator

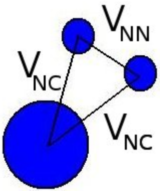
For one-body operator,

$$\begin{aligned}\langle A+2|A|A+2\rangle - \langle A|A|A\rangle &= 2\sum_{mn}\langle m|A|n\rangle \sum_{a} X^{(0)}_{an} X^{(0)}_{am} \\ &- 2\sum_{\mu\nu}\langle \mu|A|\nu\rangle \sum_{\alpha} X^{(0)}_{\alpha\mu} X^{(0)}_{\alpha\mu}\end{aligned}$$

For a two-body operator,

$$\begin{aligned}\langle A+2|O|A &+ 2\rangle - \langle A|O|A\rangle = \sum_{klmn}\langle kl|O|mn\rangle X^{(0)}_{mn} X^{(0)}_{kl} \\ &+ 2\sum_{kl\mu\nu}\langle kl|O|\mu\nu\rangle X^{(0)}_{\mu\nu} X^{(0)}_{kl} + \sum_{\kappa\lambda\mu\nu}\langle \kappa\lambda|O|\mu\nu\rangle X^{(0)}_{\mu\nu} X^{(0)}_{\kappa\lambda}\end{aligned}$$

Interactions



- neutron-neutron interaction: Gogny D1S effective NN interaction.
- neutron-core interaction: WS + particle-vibration coupling

$$U(r) = V_{WS} + \delta V, \quad \delta V(r) = 16\alpha_l e^{2(r-R)/a}/(1 + e^{(r-R)/a})^4$$

More about the correction

- α_l is angular momentum dependent. It is also energy dependent but we are interested to general and vanishes as the energy denominator increases.
- this correction is of second order and it is non-local. It has been shown that this non-locality does not play any role in the shape of the correction dominated by dU/dr. Thus we may simplify this term as $(dU/dr)^2$

- Using the RPA formalism we wish to analyse a range of Beryllium isotopes going from ^{8}Be to ^{14}Be.
- RPA applied to a ^{10}Be core (which gives information on ^{8}Be, ^{10}Be and ^{12}Be) and to a ^{12}Be core (which gives information on ^{10}Be, ^{12}Be and ^{14}Be).
- A constraint is to obtain the same results for ^{12}Be within the two calculations.
- For each isotope we determine 0^{+}, 1^{-} and $2+$ states and compare them to the experimental data.
- We determine the two-neutron separation energy, the rms , the average distance between the neutrons of the halo and the average distance between the center of mass of the halo neutrons and the center of mass of the core.

Results for ^{8}Be

- We do not find any excited 0^+ nor 1^- states at low energy. This is in agreement with the experimental results.
- We find a 2^+ excited state at 3.1 MeV instead 3.04 MeV experimentally.
- Usually, ^{8}Be is considered as a two-α system with success: Why the results obtained with ^{10}Be - 2n are in agreement with those of α - α?

What is known of ^{13}Be?

- ^{13}Be is not bound
- $5/2^{+}$ resonance at 2.0 MeV
- low-lying 1/2 state in the continuum

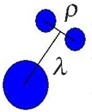
- adjust the correction to reproduce the experimental energy of $1d_{5/2}$
- the lower state of ^{13}Be is adjusted to reproduce the two-neutron binding energy of ^{14}Be.

Two scenarii for ^{13}Be

Inversion				Without Inversion			
Core							
l	j	ϵ (MeV)	α_l	l	j	ϵ (MeV)	α_l
0	1	-28.00	0	0	1	-28.00	0
1	3	-6.58	0	1	3	-6.58	0
0	1	-3.15	-23.3	1	1	-3.03	0
Continuum							
l	j	ϵ (MeV)	α_l	l	j	ϵ (MeV)	α_l
1	1	0.67	8.9	0	1	0.09	-4.4
1	3	1.20	0	1	3	1.20	0
1	1	1.27	0	1	1	1.27	0
2	3	1.83	0	2	3	1.83	0
0	1	1.97	0	0	1	1.97	0
2	5	2.00	-2.4	2	5	2.00	-2.4

Inversion vs. Non inversion

	Inversion	Experiment	Non inversion
Calculation with a ^{12}Be core			
S_{2n} ^{14}Be (MeV)	1.33	1.34±0.11	0.54
S_{2n} ^{12}Be (MeV)	3.83	3.67±0.015	1.16
rms(^{14}Be) (fm)	2.90	3.1±0.4	3.51
$\sqrt{\langle \rho^2 \rangle}$ (fm)	4.6	5.4±1	8.7
$\sqrt{\langle \lambda^2 \rangle}$ (fm)	4.0	4.5	5.6
Calculation with a ^{10}Be core			
rms(^{12}Be) (fm)	2.76	2.59±0.06	
S_{2n} ^{12}Be (MeV)	3.63	3.67±0.015	
S_{2n} ^{10}Be (MeV)	8.29	8.5	



^{14}Be

Table: 0^+ in ^{14}Be

Inversion	Experiment	Non inversion
2.74	2.56	1.71
3.11		2.71
		2.83

Table: 1^- in ^{14}Be

Inversion	Experiment	Non inversion
2.89	3.14	1.79
3.38		1.86
3.50		3.52

Table: 2^+ in ^{14}Be

Inversion	Experiment	Non inversion
3.16	1.59	2.03
3.67		2.45

The experimental 2^+ state could be $(2n)_{0+} \otimes^{12} Be(2^+)$ as ^{12}Be has a 2^+ excited state at E^* =2.1 MeV.

Outlooks

- We find good results for ^{8}Be and ^{12}Be using as input the known ^{11}Be spectrum
- We use the RPA to have a better understanding of ^{13}Be from what is already known for ^{12}Be and ^{14}Be.
- There is a good chance to have this inversion in the ^{13}Be spectrum
- Possile reaction calculation taking into account both neutrons within an Eikonal formalism